Nucleation in synoptically forced cirrostratus

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[1]   Formation and evolution of cirrostratus in response to weak, uniform, and constant synoptic forcing is simulated using a one-dimensional numerical model with explicit microphysics, in which the particle size distribution in each grid box is fully resolved. A series of tests of the model response to nucleation modes (homogeneous-freezing-only/heterogeneous nucleation) and heterogeneous nucleation parameters are performed. In the case studied here, nucleation is first activated in the prescribed moist layer. A continuous cloud-top nucleation zone with a depth depending on the vertical humidity gradient and one of the nucleation parameters is developed afterward. For the heterogeneous nucleation cases, intermittent nucleation zones in the mid-upper portion of the cloud form where the relative humidity is on the rise because existent ice crystals falling from higher nucleation zones do not efficiently deplete the excess water vapor and ice nuclei are available. Vertical resolution as fine as 1 m is required for realistic simulation of the homogeneous-freezing-only scenario, while the model resolution requirement is more relaxed in the cases where heterogeneous nucleation dominates. Bulk microphysical and optical properties are evaluated and compared. Ice particle number flux divergence, which is due to the vertical gradient of the gravity-induced particle sedimentation, is constantly and rapidly changing the local ice number concentration, even in the nucleation zone. When the depth of the nucleation zone is shallow, particle number concentration decreases rapidly as ice particles grow and sediment away from the nucleation zone. When the depth of the nucleation zone is large, a region of high ice number concentration can be sustained. The depth of nucleation zone is an important parameter to be considered in parametric treatments of ice cloud generation.

1. Introduction

[2]   The optical depth of cirrus, one of the controlling factors determining its associated net cloud radiative forcing, depends on the cloud ice water path (IWP) and effective particle size [e.g., *Foot*, 1988]. Some state-of-the-art general circulation models (GCMs) now predict hydrometeor mixing ratios [e.g., *Del Genio et al.*, 1996; *Fowler et al.*, 1996]. However, realistic prediction of cirrus optical and microphysical properties requires accurate estimation of the number concentration of ice particles generated in the nucleation regime. Using an approximate analytical solution validated by parcel model simulations, *Kärcher and Lohmann* [2002] developed a parameterization scheme for ice particle number concentration via homogeneous freezing nucleation of aerosol particles and implemented it into the European Center Hamburg (ECHAM) GCM [*Lohmann and Kärcher*, 2002] to examine the aerosol effects on the ice cloud and Earth-atmosphere radiative budgets. Despite advances in parameterization schemes of aerosol effects on ice initiation, our fundamental understanding of the evolution of synoptically forced cirrus still lags. Studies based on parcel models are typically not able to provide information about the entire cloud from cloud base to cloud top. Moreover, parcel model studies usually assume that the ice particles are lifted with the parcel (no particle fallout or fall-in) and that there is no exchange of mass or heat with the environment. Neglect of particle fallout/fall-in is questionable for weak forcing conditions, where nucleation may last several to more than 10 min. Thus a model of one-dimension (1-D) or higher [e.g., *Jensen et al.*, 1994a, 1994b; *Khvorostyanov et al.*, 2001; *Sassen et al.*, 2002] is needed to adequately estimate cloud bulk properties over the entire cloud depth. In our study a 1-D model with an explicit microphysical scheme is used to simulate a column of air lifted by a gentle updraft.

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